Optimization of the DUSEL Beam Design

DUSEL Beamline Working Group Mtg, 2/26/09

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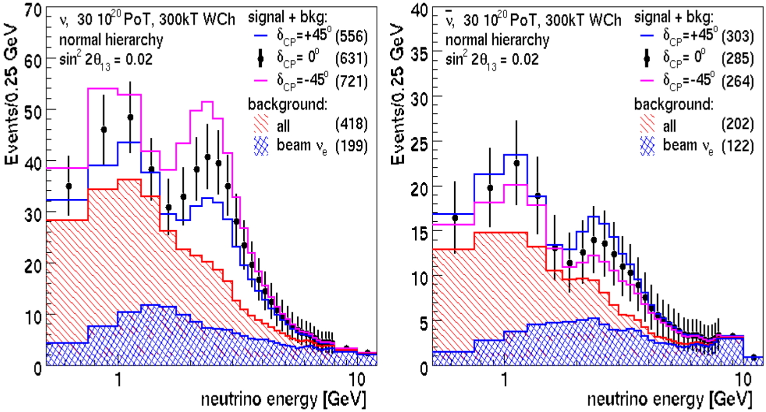
Outline

Searching for $\nu_\mu \to \nu_e$ in WCC

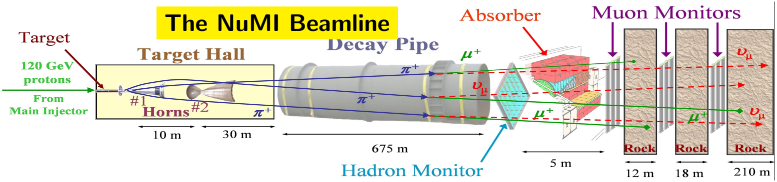
Using the 2007 DUSEL beam design and a parameterized simulation based on SuperK response for $\sin^2(2\theta_{13}) = 0.02$ after 3 MW.yr:



Can we increase the flux in the 1-7 GeV region?

Can we reduce NC bkgd by improving beam design?

Beam design strategies for DUSEL



- **Strategy 1: Increase low energy flux at the oscillation maximum through improved:**

  1a) target design
  1b) focusing
  1c) beam energy
  1d) decay pipe geometry

- **Strategy 2: Improve S:B at low energies by reducing high energy tail using:**

  2a) beam plugs,
  2b) off-axis beams
  2c) beam energy

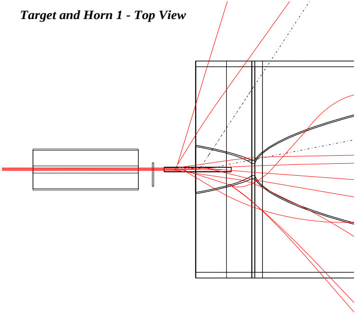
— Needs work — 50-80% done — > 80% done

Focusing system optimization

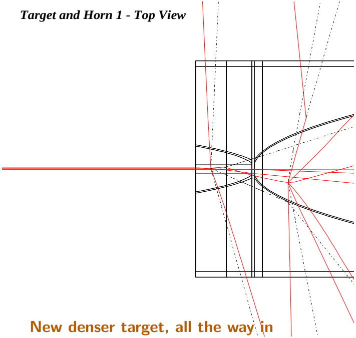
Optimization of target/focusing system design

Optimize focusing to maximize ν_μ flux at 1st and 3nd oscillation maximum using NuMI-like horns

Insert CC target (r=6mm,L=80cm,ρ = 2.1 g/cm^3) into NuMI Horn1



Default NuMI target/fin/baffle

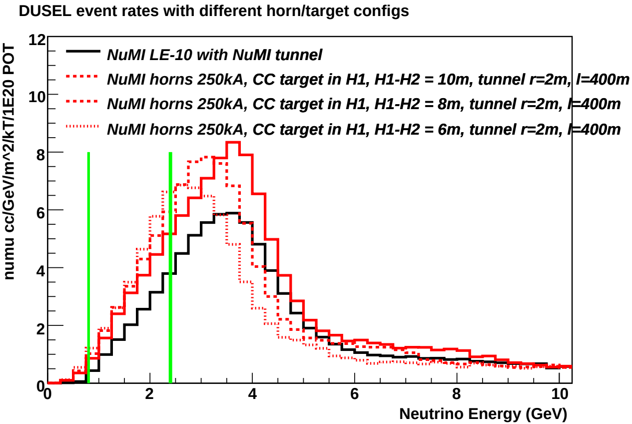


New denser target, all the way in

Fully embedding the target into the NuMI horns is the most optimal

Optimizing horn alignement

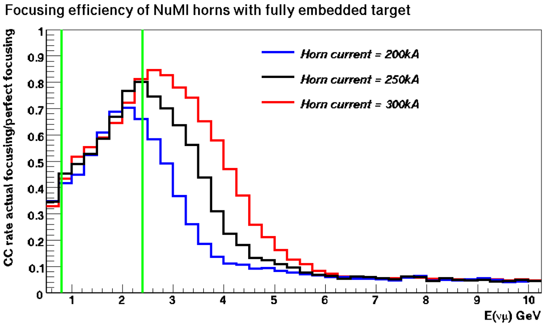
1-Decrease separation between Horn1 and Horn2 (fully embedded target)



Moving the horns closer increases the low energy flux

Optimizing the horn currents

Simulated "perfect" focusing by setting hadron $p_t = 0, p_z = p_{tot}$ at production point from target surface and using GEANT to propagate hadrons through the beamline.
With an 80cm target fully embedded in NuMI horn1, ν_μ rates at 1300km with realistic/perfect focusing are:



250 kA horn current for NuMI style horns is best.

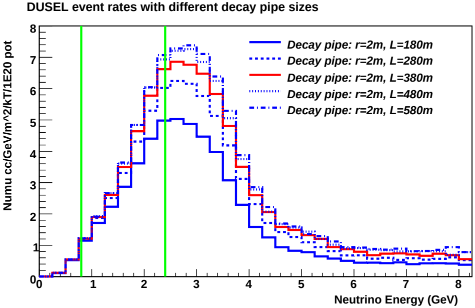
Can the low energy focusing efficiency be improved?

Decay pipe optimization

Decay pipe length optimization

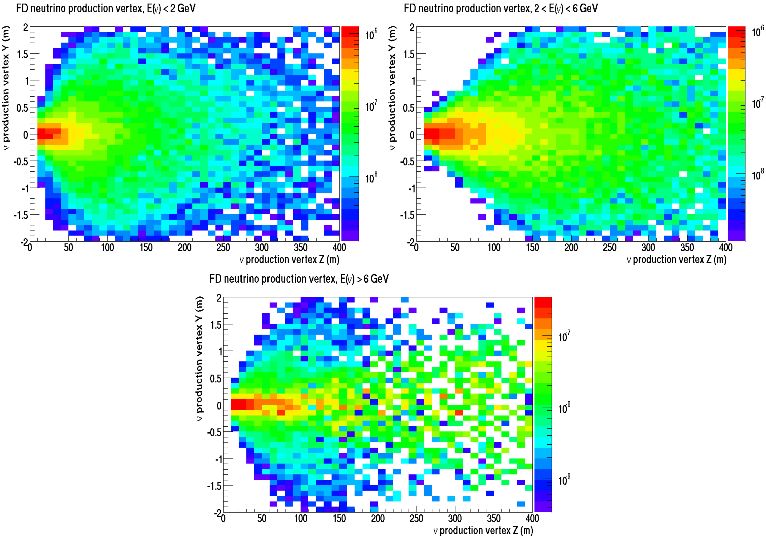
Current choice for decay pipe diameter = 4m

Optimize decay pipe length:



DP length	Rate 0 – 2 GeV	Rate 2 – 6GeV	Rate > 6GeV
180m	3.1	11	6.3
280m	3.5	14	8.1
380m	3.6	16	9.7
480m	3.7	17	11
580m	3.7	17	11

Decay pipe shape optimization



Reduce volume by using conical shapes – **See work by Byron Lundberg**

Helium in the Decay Pipe

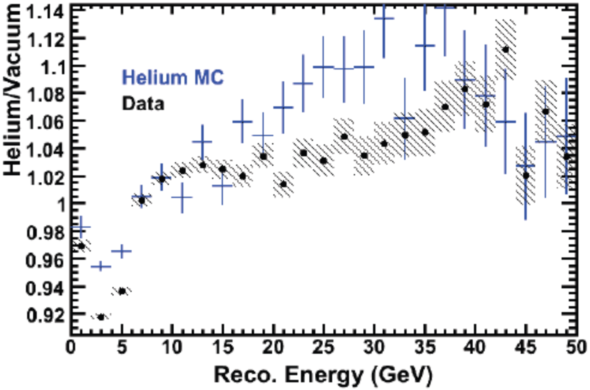
- **The decay pipe is the single most expensive element in the beamline. An evacuated DUSEL decay pipe would increase costs considerably.**
- **To reduce costs, the design will be for a He filled decay pipe at $\sim$ 1 atm.**
- **He in the decay pipe acts as an absorber - esp for lower energy hadrons, in addition you can get extra HE ν from proton beam remnant interactions with He.**

We need to assess the impact of He in the DUSEL decay pipe

MINOS lessons: He in Decay pipe

Alex Himmel

NuMI/MINOS ran Jan 25, 2005- August 2007 with an evacuated decay pipe (0.4 Torr). In September 2007, filled with He at 682.6 Torr (0.9atm).



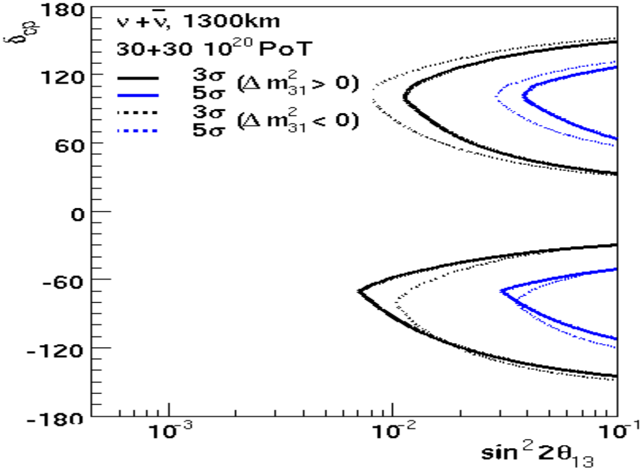
MINOS data: 2-3% increase in HE tails with He

DUSEL: This effect is dependant on decay pipe geometry

The Tale of HE Tails

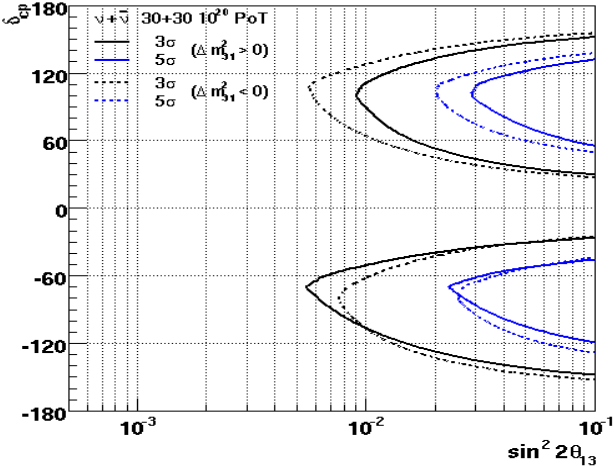
CPV sensitivity with smaller backgrounds

Mark Dierckxsens



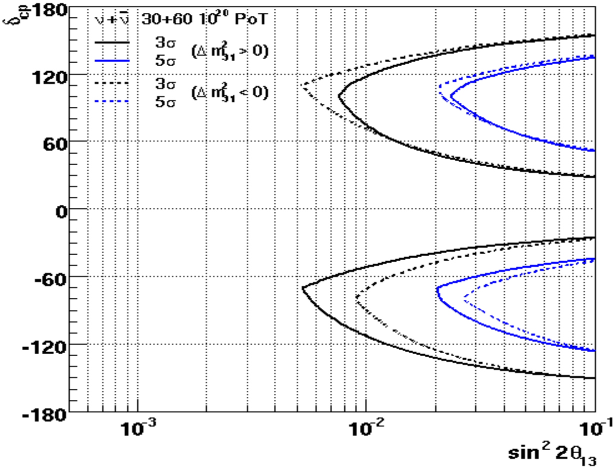
Sensitivity with std background, 10% uncertainty

CPV sensitivity with smaller backgrounds



Sensitivity with 1/2 background, 10% uncertainty

CPV sensitivity with smaller backgrounds



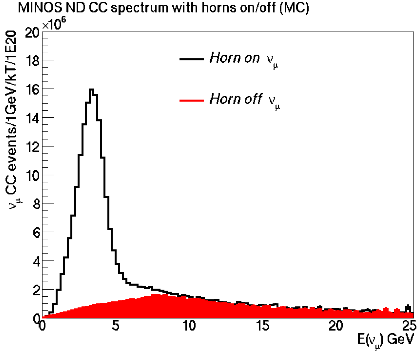
Sensitivity with default background, 10% uncertainty, double $\bar{\nu}$ exposure

CPV sensitivity with smaller backgrounds

For CPV sensitivity

1/2 background $\sim \bar{\nu}$ exposure $\times 2 \equiv$ 3 MW.yrs

NC backgrounds in the MINOS ND Data

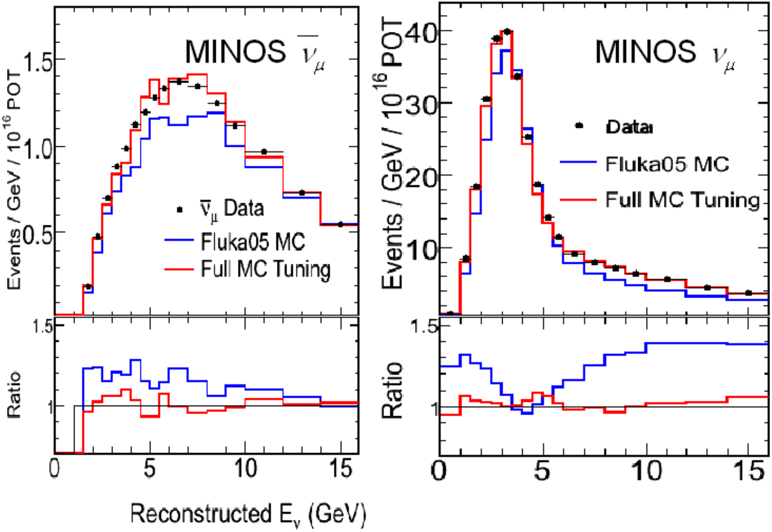


In the MINOS ND data we measured the background composition of ν_e selected events with horn on/off in the region 1-8 GeV.
SEE MAYLY SANCHEZ's W&C TALK TOMMOROW.

$$\frac{\text{NC from tails}}{\text{All NC}} \sim \frac{\text{NC horn off}}{\text{NC horn on}} \sim \mathbf{0.5 - 0.6}$$

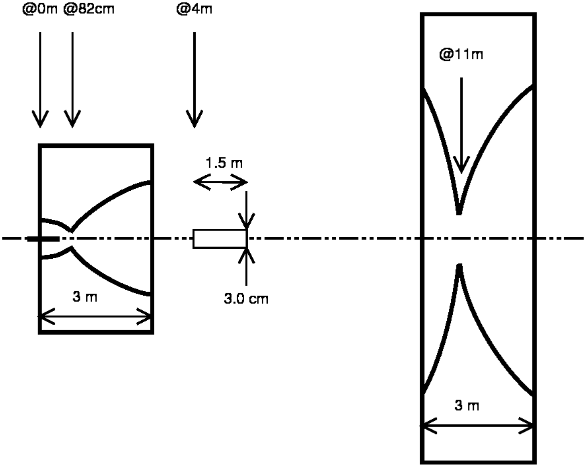
MINOS measurement of HE tails

Zarko Pavlovic



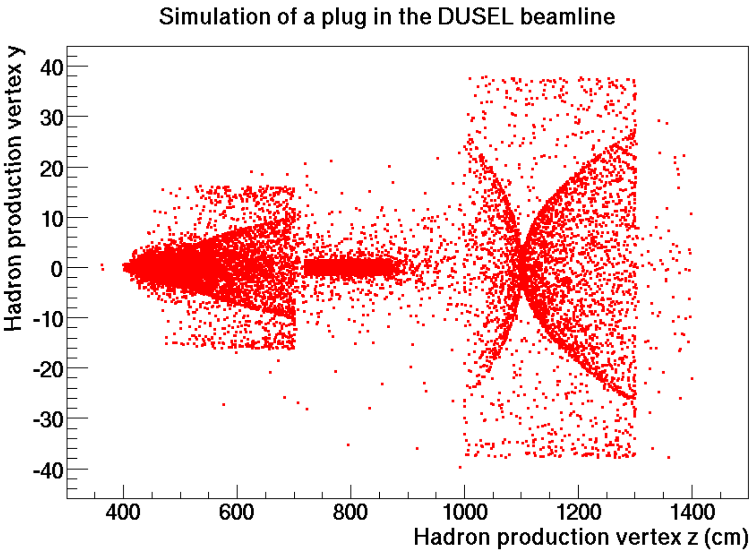
MINOS data 20% more HE νs compared to Fluka05 MC

Whats a beam “plug”?

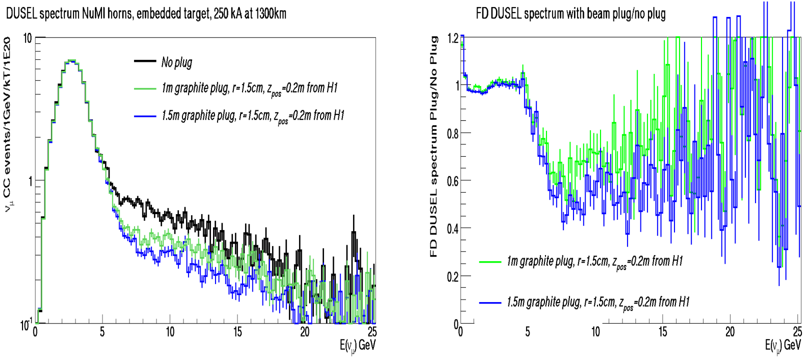


In 2001, Brett Viren (following up on studies at IHEP) found that a 1.5cm radius graphite target placed between the 2 horns reduced the high energy tails in NuMI LE beam by $>$ 30 %.

Adding plugs to NuMI/DUSEL



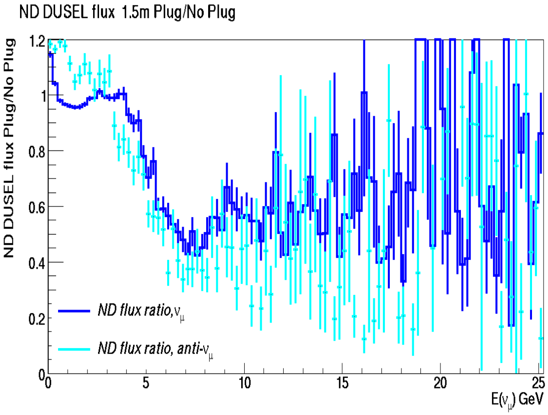
DUSEL spectra with different plugs



With 1.5m plug

$$\frac{\text{plug}}{\text{no plug}}(> 5\text{GeV}) = 0.62 \qquad \frac{\text{plug}}{\text{no plug}}(< 5\text{GeV}) = 0.99$$

Enhanced production of $\bar{\nu}, \nu_e$ with plug



$\bar{\nu}$ contamination in the ν beam $<$ 3 GeV increases by 10%

$\nu_e + \bar{\nu}_e$ contamination in the ν beam $<$ 5 GeV increases by 6%

Beam plugs Pros and Cons

Pros:

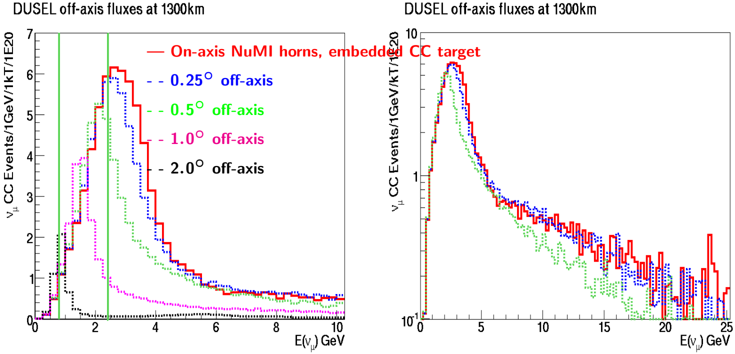
- **Most effective tool that reduces the HE flux exactly where you need it > 5 GeV without any impact at low energy.**
- **Might give you more ν at very low energies < 0.5 GeV - good for solar oscillations.**
- **Tunable - different plugs can be used.**

Cons:

- **Requires expensive material R&D and engineering**
- **Complicates operating - need to change out plugs.**
- **Complicates beamline geometry for Near-Far extrapolation**

Going off-axis

Another alternative to cutting down the high energy tails is going off-axis - redo calculation with optimized on-axis beam:



On axis flux is best for broad-band coverage

Off-Axis Pros and Cons

Pros:

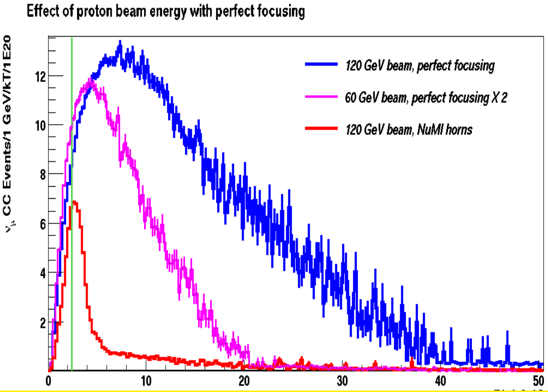
- **Effective at reducing HE tails.**
- **At high angles $> 1^\circ$ enhances flux at the 2nd oscillation maxima.**
- **NuMI/MiniBoone data confirms simulation predictions off-axis**

Cons:

- **Throwing away beam flux at 1st osc maximum**
- **Limited tunability - WE CANT MOVE THE BEAMLINE!**
- **Limited broad-band spectrum.**

Impact of primary proton energy on spectrum

Optimize the primary proton beam power using “PERFECT” focusing (no horns, set all hadron $p_T = 0$).



Lowering the beam energy is very effective at reducing HE tails and increases flux at lower beam energies

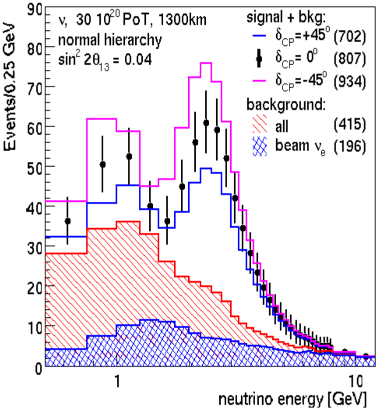
BUT must not sacrifice power!

FD spectra with latest optimization

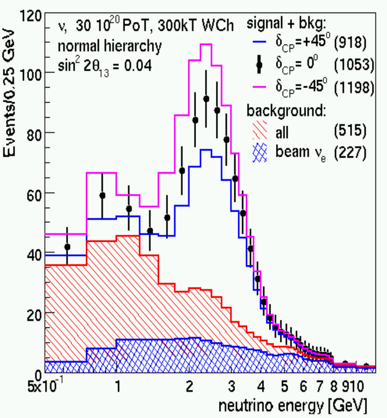
Embedded CC target in NuMI horns with 6m separation, cylindrical decay pipe with 4m diameter, 380m length, 120 GeV beam.

WCC spectra

Old DUSEL design

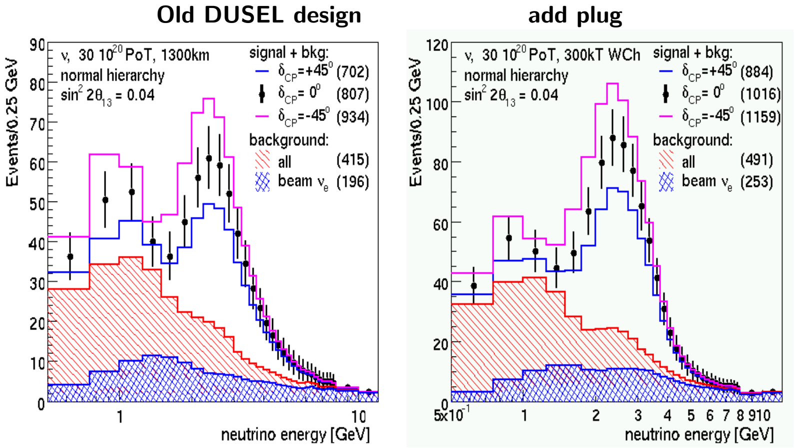


New design



WCC spectra

Mark Dierckxsens



Summary and Conclusions

Summary - improved performance

Signal type	Old oa flux	New focusing	With plug
ν_e signal δ_{cp}=+45	295	403	393
ν_e signal δ_{cp}=0	395	538	525
ν_e signal δ_{cp}=-45	509	683	669
NC bkgd	202	273	224
beam ν_e bkgd	196	227	253
numu	15	15?	15

Flux in the signal region by 30% compared to previous designs

- Used NuMI horns (known performance) and optimized current and alignment for DUSEL beam.
- Fully embedded target into Horn 1
- Increased horn current from 185kA (current NuMI) to 250kA.

Summary - lowering backgrounds

HE tails contribute 50-60% of NC background for ν_e appearance

HE tail ($>$ 5 GeV) adjustments to Fluka05 MC

Adjustment	Effect	Comment
MINOS beam fit (Data)	$\sim$ +20%	10% more flux at $<$ 5 GeV
He in beampipe (Data)	+3%	different beampipe geometry
1.5 m graphite plug (MC)	-38%	LE unchanged
0.5° off-axis (MC)	-38%	Less coverage at 1st maxima
p-beam 120 $\rightarrow$ 60 GeV	$-46\%^{**}$	At the same power

** Estimated using AGS focusing not NuMI

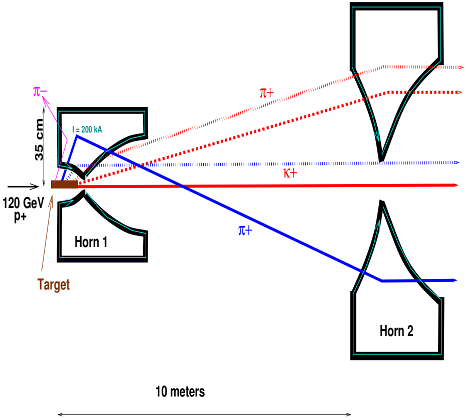
With 120 GeV protons, plug is the best option for lowering HE tails

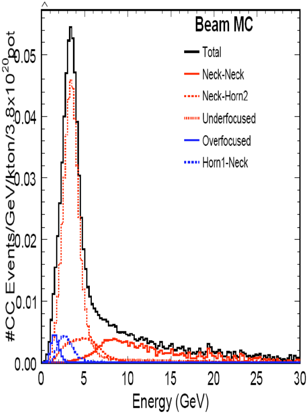
Whats next?

- **Optimize beam energy in the range 90-120GeV**
- **Waiting for results of MINOS efforts to model He in decay pipe using Fluka08 to finish He study.**
- **Continue study tunability of plugs - should we have a plug moves along the beam axis? Early studies indicate this changes where the cuttoff in energy starts.**
- **Move horns even closer?**
- **Target material and geometry optimization (Jim Hylen & Byron Lundberg)**
- **After Byron and Jim agree on a beam pipe shape - put all effects in MC: MINOS ND data corrections, correct target material, He in beam pipe, best plug and/or off-axis angle, decay pipe optimized to reduce volume. RECALCULATE SENSITIVITIES.**
- **Suggestions, please?**

Breakdown of NuMI spectrum

Zarko Pavlovich



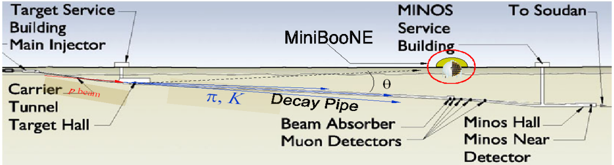


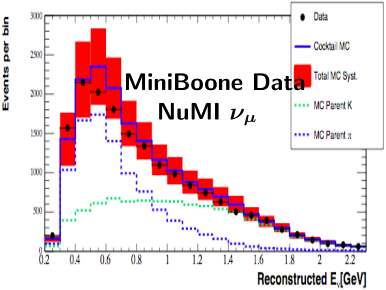
High energy ν come from hadrons exiting horn 1 on-axis

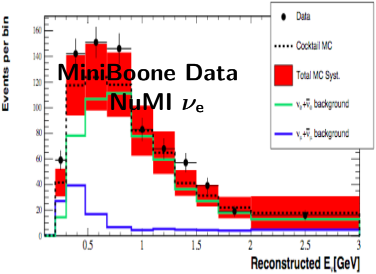
Measurement of NuMI off-axis with MiniBoone

Zelimir Djurcic

The MiniBoone detector is located at an angle of 110mrad off-axis from the NuMI beam 745m downstream of the NuMI target.







First measurement of an off-axis beam - good agreement with prediction